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NAVAL AIR DEVELOPMENT CENTER

Johnsville, Warminster, Pennsylvania

Report No. NADC-AE-6857 20 MAY 1969

Ka-BAND RADOME DESIGN

PHASE REPORT
AIRTASK NO. A31533E01/2021/R008-01-01
Work Unit No. 48

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DEPARTMENT OF THE NAVY
NAVAL AIR DEVELOPMENT CENTER
JOHNSVILLE
WARMINSTER, PA. 18974

Aero-Electronic Technology Department

REPORT NO. NADC-AE-6857 20 May 1969

Ka-BAND RADOME DESIGN

PHASE REPORT
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Standard and nonstandard types of radome wall structures are discussed to aid in determining practical design concepts for radar systems operating at Ka-band frequencies. Transmission efficiencies of selected radome panels are illustrated and compared for a hypothetical radome design problem.

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SUMMARY

INTRODUCTION

AIRTASK No. A31533E01/2021/R008-01-01, Work Unit No. 48, was established for the purpose of conducting research on concepts for Ka band radome design.

The Ka-band of frequencies represents the lower end of a large group that operates with millimeter wavelengths. Because of the difficulty in building conventional radomes of sufficient strength and transmission properties for radar systems operating in these bands, new radome design techniques must be found. Standard type radomes have some limited usage for Ka-band radar systems. This report presents an analysis of selected standard and nonstandard approaches to the design of Ka-band radomes.

RESULTS AND CONCLUSIONS

Results of this study indicate that:

1. First-order* Ka-band radomes do not have the physical strength for general usage on aircraft.

2. A full-wave solid wall of reinforced plastic can provide a radome for some Ka-band systems. A third-order*, solid-plastic radome would provide a marginal electrical design.

3. The A-sandwich, thin-skin radome is not compatible with Ka-band radar. An A-sandwich radome with half-wave skins can be used with radar operating at Ka-band and higher frequencies.

4. The B-sandwich concept (limited to low-dielectric skin materials) can be applied to the design of Ka-band radomes.

5. Bi-layer and tri-layer radome wall construction using half-wave veneers can be used with radar systems operating in narrowband millimeter wavelengths.

6. A multi-layer radome wall structure could extend the operating frequencies of a Ka-band radar system.

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* *Transmission of power is of a periodic nature and varies as the wall thickness (or any veneer) of the radome is expanded. The equation to optimize transmission through a solid homogeneous radome is: Wall thickness =* $n\lambda/(2\sqrt{\epsilon - \sin^2\theta^1})$. *The order refers to the choice for the value of n.*

RECOMMENDATIONS

The full-wave wall of a low-loss dielectric material is recommended in the design of Ka-band radomes. It offers the simplest solution, provided the strength is adequate and that approximately 0.75- to 1-db loss in transmission (one way) can be tolerated. Composite types using quarter-wave and half-wave veneers can provide better electrical performance at a higher cost.

For designs of radomes for millimeter wavelengths above Ka-band, new techniques should be explored.

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LIST OF SYMBOLS

d	=	Thickness of variable layer (inches)
IPD	=	Insertion phase delay (radians)
$T_{\perp}^2$	=	Power transmission coefficient (perpendicular polarization)
X	=	Panel wall thickness (inches)
$\tan \delta$	=	Dielectric loss tangent
ϵ	=	Dielectric constant
θ	=	Angle of incidence (degrees)
λ	=	Free-space wavelength

SCOPE OF ANALYSIS

In an airborne radar system, the choice of millimeter wavelengths can provide a high-resolution system in a relatively small space on the airframe. The design and fabrication of a radome for such a system are more difficult than for systems operating at lower frequencies. The scope of this report is limited to the design of radomes to be used at the lower end of the millimeter wavelength region of the electromagnetic frequency spectrum, specifically the Ka-band, which has free-space wavelengths less than a centimeter.

Transmission measurements through flat panels of standard and non-standard types of radome wall structures are plotted herein as aids in selecting usable Ka-band radomes. Selected dielectric materials applicable to radome construction are to be found in table I. The shape of the radome depends on the choice of position on the airframe and the required aerodynamic fairing. This implies that the wavefront will usually strike the radome surface at varying angles of incidence. Therefore, the examples of reasonable radome wall designs do consider minimizing the difference in the insertion phase delay (IPD) for the spread of incidence angles anticipated for the radome geometries. If a curved radome provides good transmission of power, and the phase alignment approaches that of the initial wavefront, the pattern distortion is minimal. A frequency of 35 ghz (free-space wavelength of 0.337 inch) is assumed in the theoretical transmission plots comparing the different wall types.

Throughout this report, the more critical case of incidence at perpendicular polarization is assumed in determining transmission. If the radome and the placement of the antenna can be restricted to permit incidence at parallel polarization only, excellent transmission can usually be obtained over a broad frequency band and wide range of incidence angles. A broader tolerance in construction is available under this restriction.

TABLE I

TYPICAL RADOME DIELECTRIC MATERIALS

Relative Dielectric Constant	Material
1	Air
1.2	Plastic Foam (Polyurethane); Plastic Honeycomb (Phenolic)
2	Teflon
2.3	Ceramic Foams
2.6	Polyphenylene Oxide
2.7	Plexiglas
3	Neoprene; Vinyl Molding Compound
3.8	Fused Silica
4	
4.2	Polyester Fiberglass Laminate
4.5	Polybenzimidazole (Imidite) Fiberglass Laminate
4.9	Furan Epoxy Fiberglass Laminate
5	
5.5	Corning (9606) Pyroceram (Glass-Ceramic); Cordierite
6	Beryllia
6.6	Corning (0120) Glass
7	
8	
8.1	Coors (AD-85) Alumina
9	
9.6	Coors (AD-995) Alumina

D E S I G N   A P P R O A C H E S

SOLID DIELECTRIC PANELS

Glass-reinforced plastic is a commonly used radome material. This material forms a homogeneous composite that has a dielectric constant of approximately 4.15 and a loss tangent that remains close to 0.015. Figure 1 illustrates the percentage of generated power that is transmitted through panels of various thicknesses of this reinforced plastic material for several angles of incidence of radiation. Note that the recurring peak values for transmission at each angle of incidence remain close together out to the third order, and that there is a reduction in power with an increase of the order as a result of heat losses in the material.

Thin Wall

The so-called thin-wall panels (zero order) are extremely thin and have very little strength for aerodynamic loadings. It is conceivable, however, that electromagnetic windows this thin (0.015 to 0.020 inch) could be used in side- and aft-looking radar systems on an aircraft. For radiation near normal incidence, the expected transmission of power through these electrically thin windows would be approximately 70 to 80 percent.

Half-Wave Wall

The half-wave wall (first order) is also thin. The effectiveness of its use as a window on high-speed aircraft would depend on the window being in a protected location. The design thickness of such a radome would be 0.085 to 0.095 inch, according to the variation of incidence angles that must be accommodated in allowing full mobility of the radar antenna. The power transmitted would exceed 84 percent of incident power for a wall span of 0.095 inch for angles up to 70 degrees. The IPD of zero incidence and that of the maximum angle differ by 0.75 radian for the 0.095-inch panel, and by only 0.3 radian for the 0.085-inch panel. The design for a specific radome shape for half-wave wall would have a minimum pattern distortion if the 0.085-inch wall were used, provided of course, that little power is transmitted at incidence angles above 50 degrees.

Full-Wave Wall

The full-wave wall (second order) of reinforced plastic has sufficient strength for most Ka-band radome applications. The transmission is slightly lower compared to a half-wave wall, because of the increased heat loss through the additional material. Also, it is more difficult to design a constant wall thickness to provide adequate transmission through a broad spread of incidence angles. Nevertheless, a wall design of 0.185 inch would permit transmission through angles of incidence from

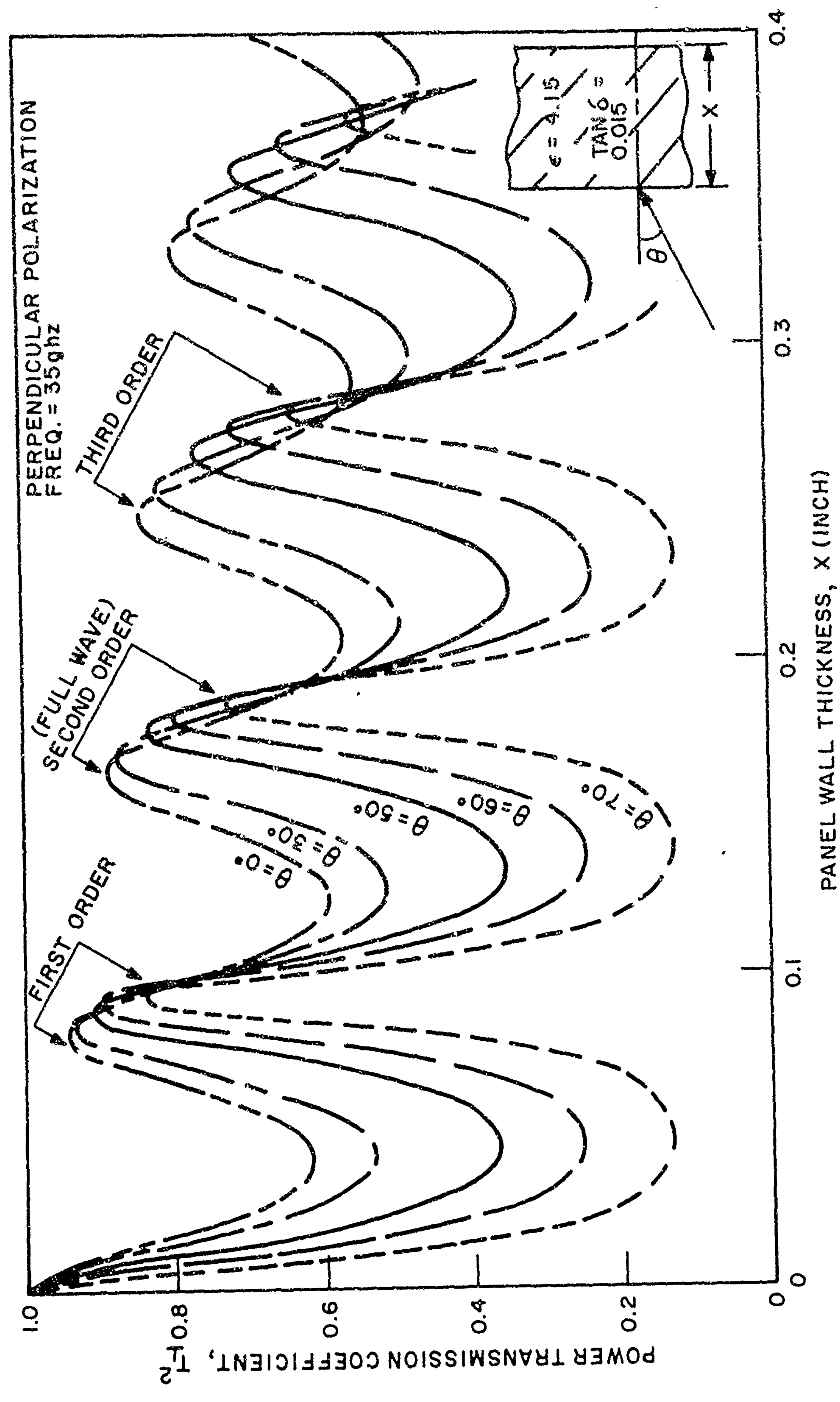

FIGURE 1 - Transmission Through a Solid Dielectric Panel

0 to 70 degrees at a loss of only 1.5 db or less. There is also an increased difference in the IPD between minimum and maximum angles over the half-wave design.

Solid plastic radomes of increasing orders are much more difficult to design, and their effectiveness is marginal. Transmission at the peak thicknesses (optimum for specific incidence angles) declines gradually for higher orders, and a given choice of wall thickness will permit less variation in the incidence of radiation.

Figure 2 compares four usable, uniform, solid-plastic radome wall designs for a hypothetical case. It assumes the shape of the radome is such that the angles of incidence are between 0 and 60 degrees. The permissible loss in transmission (one way) is assumed to be 1.5 db. Clearly, the optimum electrical design is the half-wave wall (0.090 inch), wherein approximately 90 percent of the power would be transmitted regardless of the orientation of the antenna enclosed in the window. In this design, the IPD curve is relatively flat over the span of incidence considered. The second choice is the full-wave wall, which is obviously physically stronger, and permits transmission greater than 82 percent of the power out to an incidence angle of 50 degrees. Here, the minimum transmission of power would occur at the maximum angle of incidence, which would be 70 percent ($\sim$1.5 db). In this design, the slope of the IPD curve is not severe; therefore, a small distortion of the wave front is anticipated. Both the half-wave and the full-wave wall designs are superior to the thin-wall (0.015-inch) design in transmission effectiveness. The 0.015-inch wall has the minimum spread in IPD. It is physically thin for plastic construction, but it is not electrically thin. Figure 2 also shows a third-order radome, which illustrates a strong wall that is a marginal electrical design.

DIELECTRIC SANDWICH PANELS

A-Sandwich

The majority of the sandwich radomes built for aircraft are of the symmetrical A-sandwich type. They have two thin outer skins of a solid dielectric material separated by a lightweight, low-dielectric core material. This type of construction provides a high strength-to-weight ratio and good electrical qualities for X-band and lower frequencies. Usually, the A-sandwich is highly competitive with the solid-wall type radomes discussed previously. In the classic A-sandwich, reflections from the two skins cancel when they are spaced an integral number of quarter-wavelengths. The skins cannot remain exactly a quarter-wave apart over a frequency band or a range of angles. Thin skins and low-dielectric cores produce reflections small enough that the skins need not be exactly a quarter-wave apart to produce an acceptable transmission level.

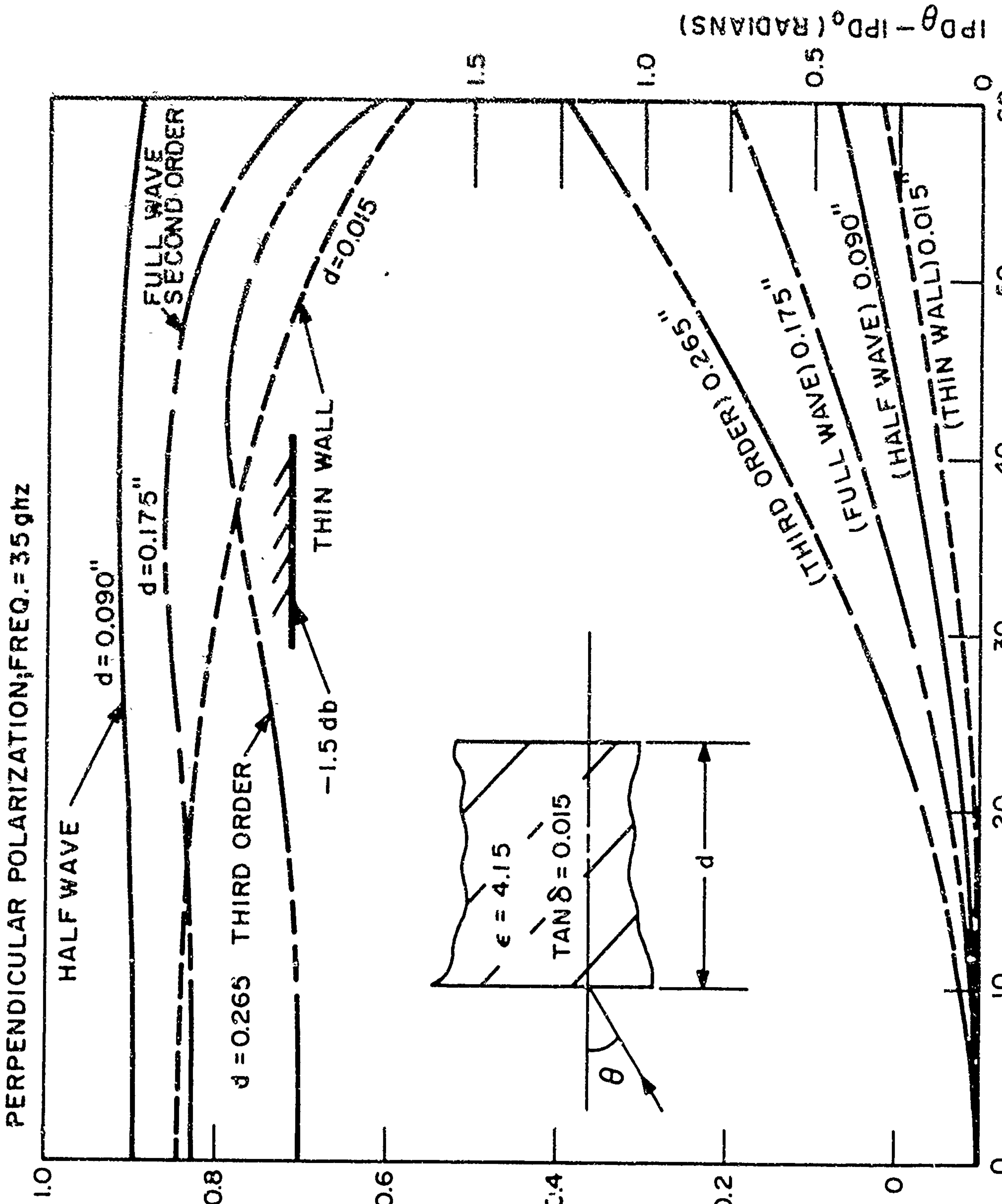

FIGURE 2 - Transmission and IPD Measurements Through Solid Plastic Panels

The skins should be very thin electrically so the reflections from each face of a skin are nearly 180 degrees out of phase. (For Ka-band thin electrically means extremely thin physically, on the order of 0.010 inch or less. Even this is not satisfactory at high angles of incidence, where electrical thickness is a rapidly changing function.) The core dielectric constant should be low so the reflection from the air-skin interface is nearly equal to the reflection from the skin-core interface.

To evaluate the use of the standard A-sandwich radome in the Ka-band, it is reasonable to assume and analyze a conventional construction using a reinforced plastic skin material with a dielectric constant of 4.15 and a core of plastic honeycomb construction with a dielectric constant of 1.25. Figure 3 illustrates transmission through a panel of such design with a skin thickness of 0.033 inch. The abscissa is the variation of the core thickness. Unlike the transmission plot of a solid wall with variable span, only the first-order peak values remain close enough to choose arbitrarily a unique core span to accommodate variable incidence of radiation. Assume that an A-sandwich radome is to be designed to satisfy the hypothetical problem investigated in the solid-wall study. The choice of a core span of 0.020 inch would transmit from 86 to 92 percent of the power generated for variable incidence from 0 to 60 degrees. The overall physical thickness of the sandwich, however, is only 0.086 inch, and it would have less strength than the first-order solid wall built of the same material as the skin of the sandwich. A survey of the second order clearly indicates that no unique core span will transmit sufficient power over the span of incidence considered for the design. The curves of figure 3 show clearly the penalty imposed by the 0.033-inch skins that are not electrically thin.

<u>Half-Wave-Skin Sandwich</u>

The concept of using a sandwich-type radome structure to obtain strength by increasing the wall span while maintaining low weight, need not be abandoned. A half-wave wall of the reinforced plastic designed for transmitting Ka-band at high incidence is approximately 0.090 inch. If the skins of the A-sandwich radome are replaced by half-wave spans, the radome will have greater strength and can be applied to Ka-band and higher frequencies. Figure 4 is a transmission plot through this type of wall construction. It is interesting to note that this plot shows that transmission at most angles of incidence is rather insensitive to the choice of core size. The peak values of the curves are affected by the absorption of energy passing through the skins. The low values of transmission for each angle of incidence through this type sandwich match closely the transmission through a homogeneous span of the core material itself. Another example is to replace the plastic skins with half-wave walls of a relatively lossless media. Figure 5 displays the transmission through such a sandwich using pyroceram (ε = 5.55, tan δ = 0.0002) for the half-wave skins. This extremely low-loss material permits the peak values of transmission for each incidence angle to approach unity coefficient.

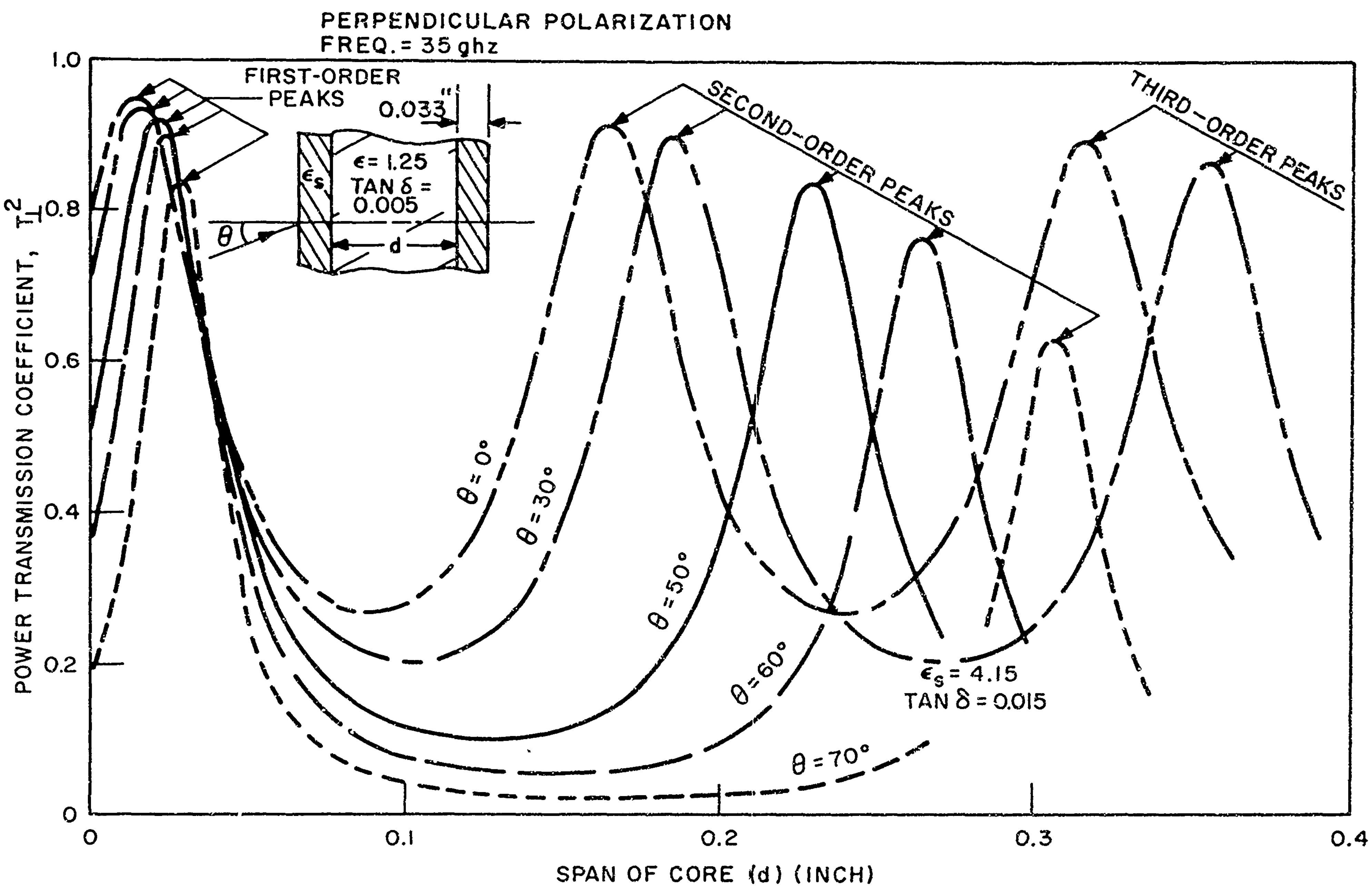

FIGURE 3 - Transmission Through an A-Sandwich Dielectric Panel

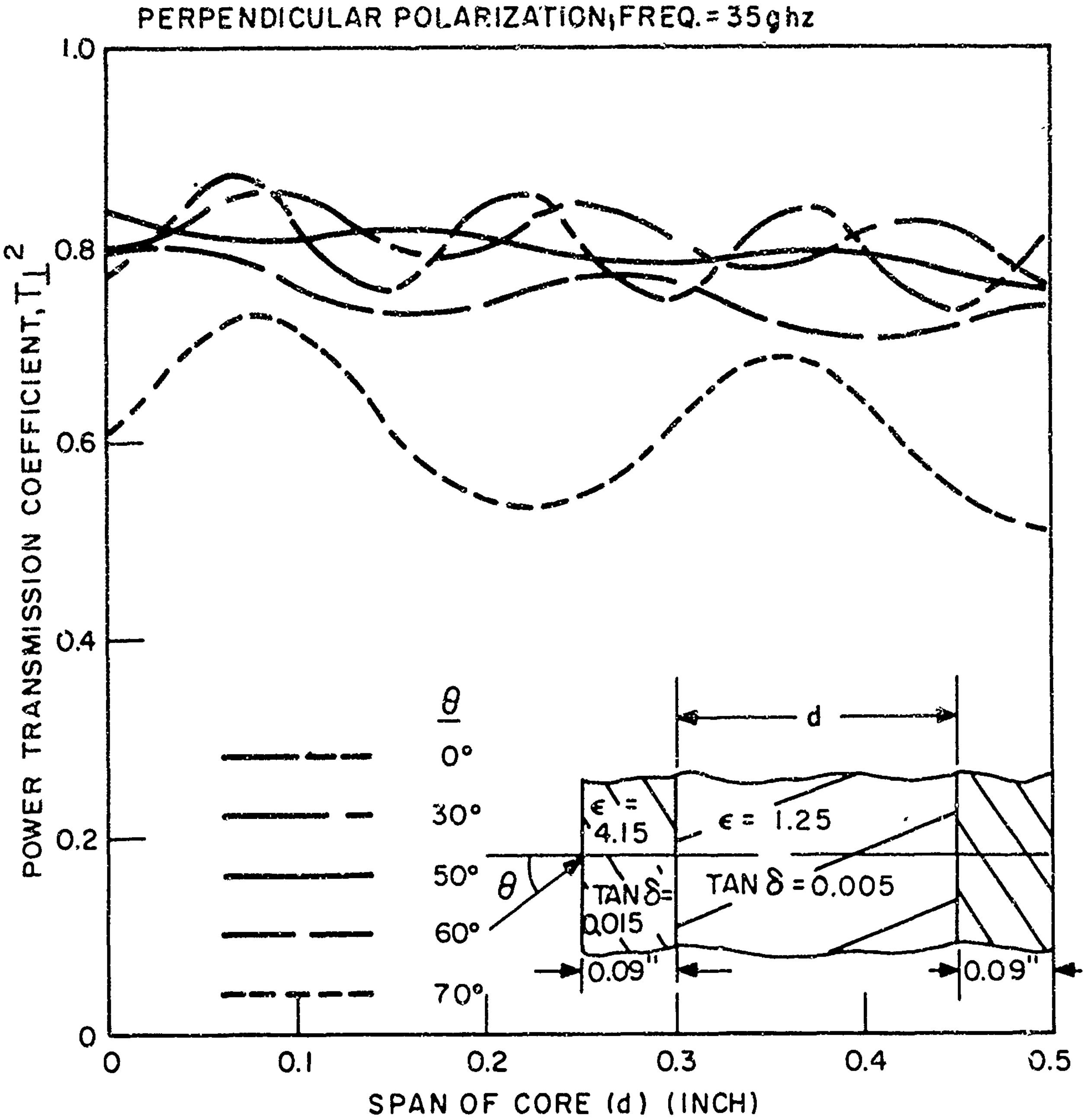

FIGURE 4 - Transmission Through Dielectric Sandwich Panel With Half-Wave Skins (Skin Dielectric 4.15)

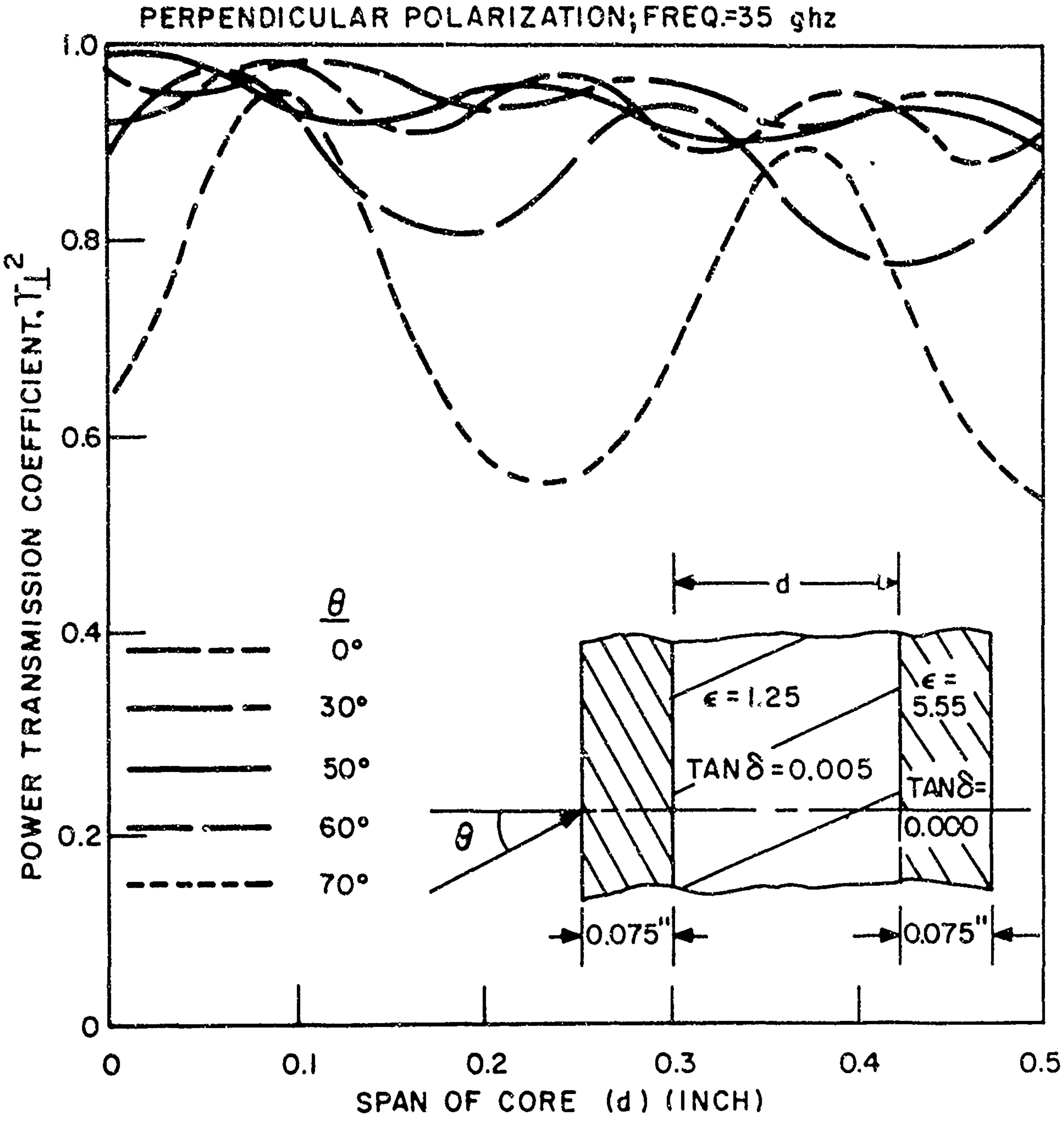

FIGURE 5 - Transmission Through Dielectric Sandwich Panel With Half-Wave Skins (Skin Dielectric 5.55)

Again, assume the hypothetical design problem used in the solid-wall analysis. A core span of 0.250 inch is a convenient choice. Figure 6 illustrates the transmission through a panel of this core with half-wave pyroceram skins. Two other core sizes are plotted for comparison to reveal the small change in transmission that occurs if the core tolerance is ±0.025 inch. A phase delay difference plot is also included. In comparing both sandwich designs, the low-loss quality of the pyroceram skin sandwich is preferable.

B-Sandwich

The B-sandwich has intrigued the radome engineer since its inception[1] in 1948. It consists of a high-dielectric core faced with low-dielectric skins, it is the reverse order of the A-sandwich. The excellent electromagnetic properties of the B-sandwich are obvious to anyone familiar with the use of lens coatings on optical instruments. The low-dielectric skins act as quarter-wave matching transformers; herein lies the major objection to most B-sandwich proposals, because the low-dielectric materials of the skins are usually less durable when exposed to the flight environment.

A Chebyschev or Butterworth transformer synthesized to match free space to a panel made of reasonable dielectric materials will have the low-dielectric-constant layer at the surface. Its dielectric constant will approach unity as the number of sections increases. Unfortunately, most durable materials have dielectric constants above 2. Because of this material limitation, transformer matching with dielectric layers is limited to one or two sections. One-section Chebyschev and Butterworth transformers are identical. The structure is known as a B-sandwich. Other transformer types would behave similarly.

Although the classic filter synthesis, when applied to radome design, leads to a fragile structure (primarily because of the use of low-dielectric skin facings), the filter theory can provide direction to radome design efforts. Low-dielectric quarter-wave skins improve the electrical performance of a dielectric wall (core) over a range of frequencies and angles of incidence as the core-skin relationship approaches the classic filter. For figures 7 through 11, a wall span of 0.140 inch is chosen, and the core (0.020 inch) is permitted five discrete dielectric values: $\epsilon = 2.5; 5.0; 7.5; 10.0; 12.5$. It is apparent that the best broadband condition occurs when the dielectric constant of the core is some value that lies between 7.5 and 10.0. (See figures 9 and 10.) The dielectrics in these graphs are near the classic matching network (B-sandwich radome).

It is interesting to note that for a given basic wall material, the skins (matching transformers) can either be used with the basic material as a core, or the basic material can be used as a quarter-wave transformer

1. *McMillen, E. P., 1966: Personal Notes on Early Radome History; Techniques for Airborne Radome Design, Vol I: Air Force Avionics Laboratory, WPAFB Report No. AFAL-TR-66-391: pp 11 and 21.*

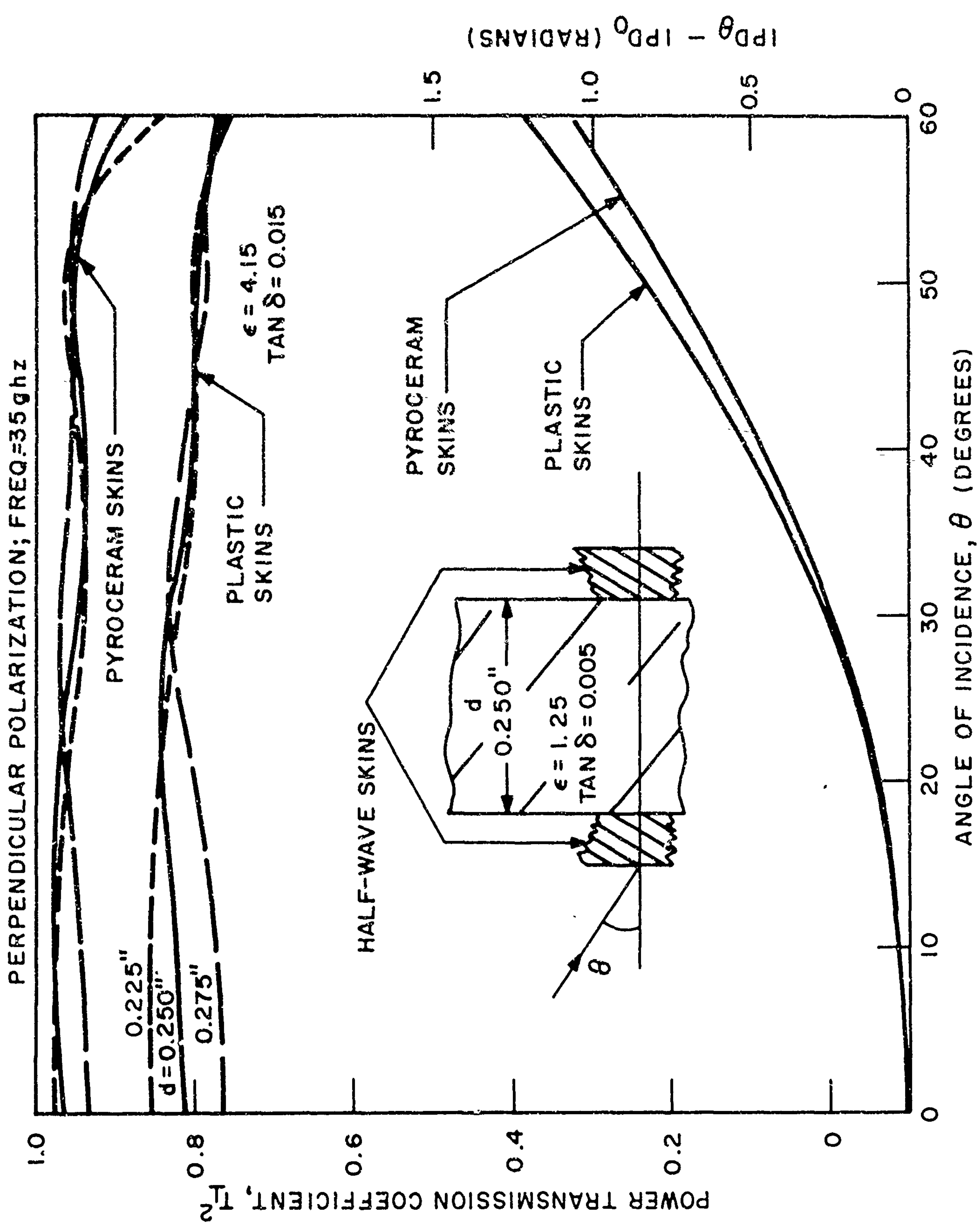

FIGURE 6 - Transmission and IPD Measurements Comparing Two Half-Wave-Skin Dielectric Sandwich Panels

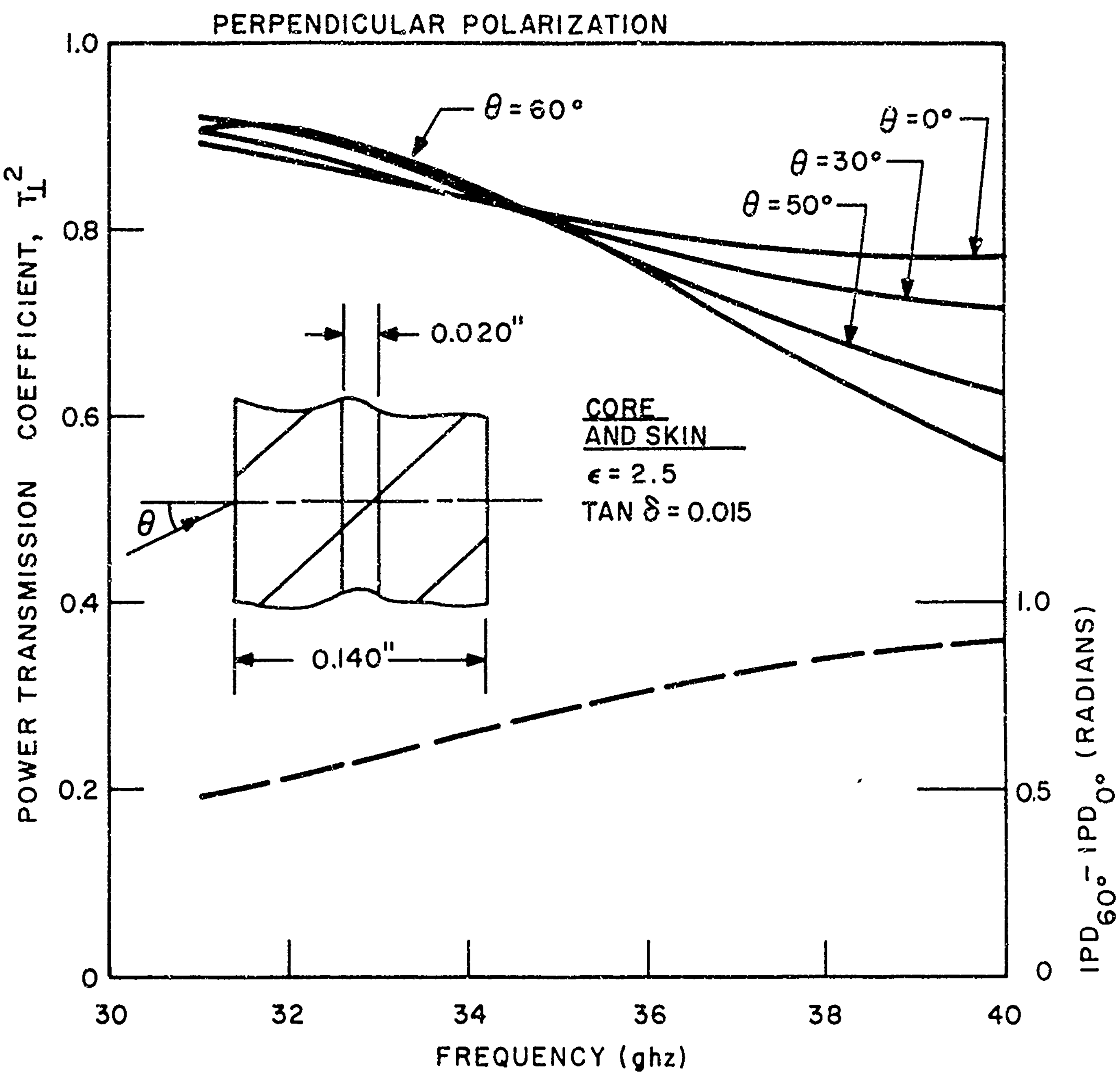

FIGURE 7 - Transmission and IPD Measurements Through Quarter-Wave-Skin Sandwich Panel (Core Dielectric 2.5)

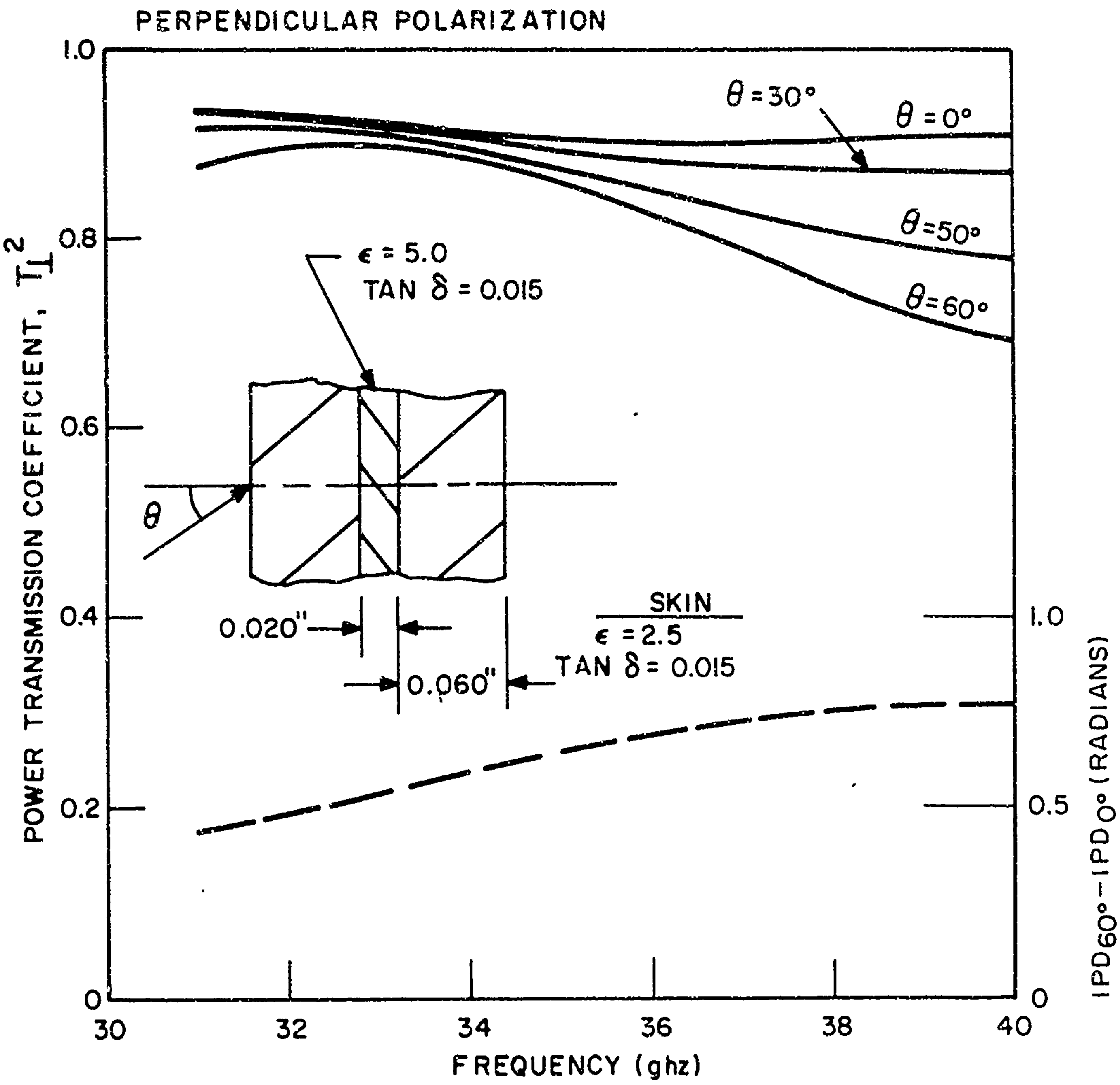

FIGURE 8 - Transmission and IPD Measurements Through Quarter-Wave-Skin Sandwich Panel (Core Dielectric 5.0)

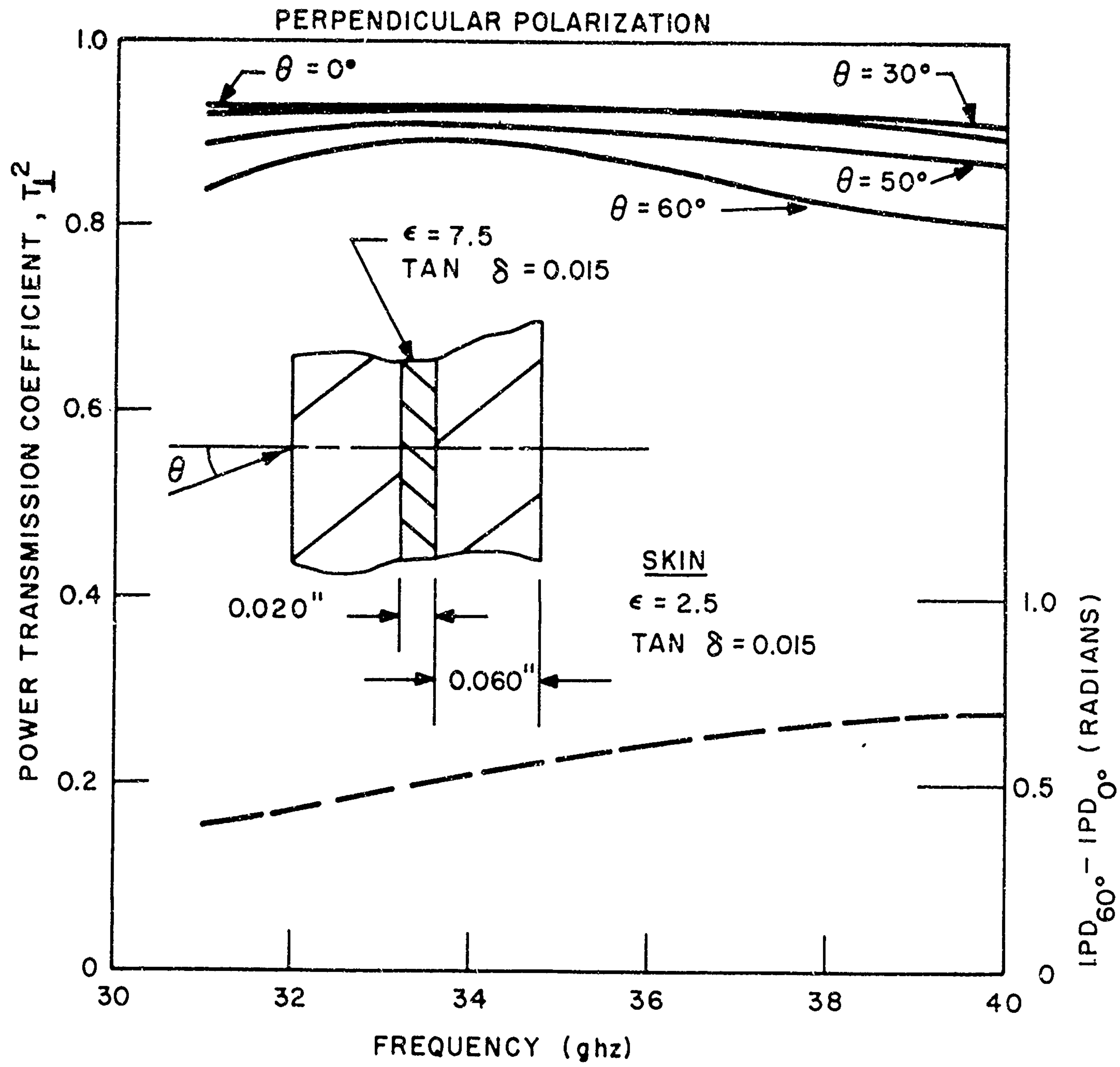

FIGURE 9 - Transmission and IPD Measurements Through Quarter-Wave-Skin Sandwich Panel (Core Dielectric 7.5)

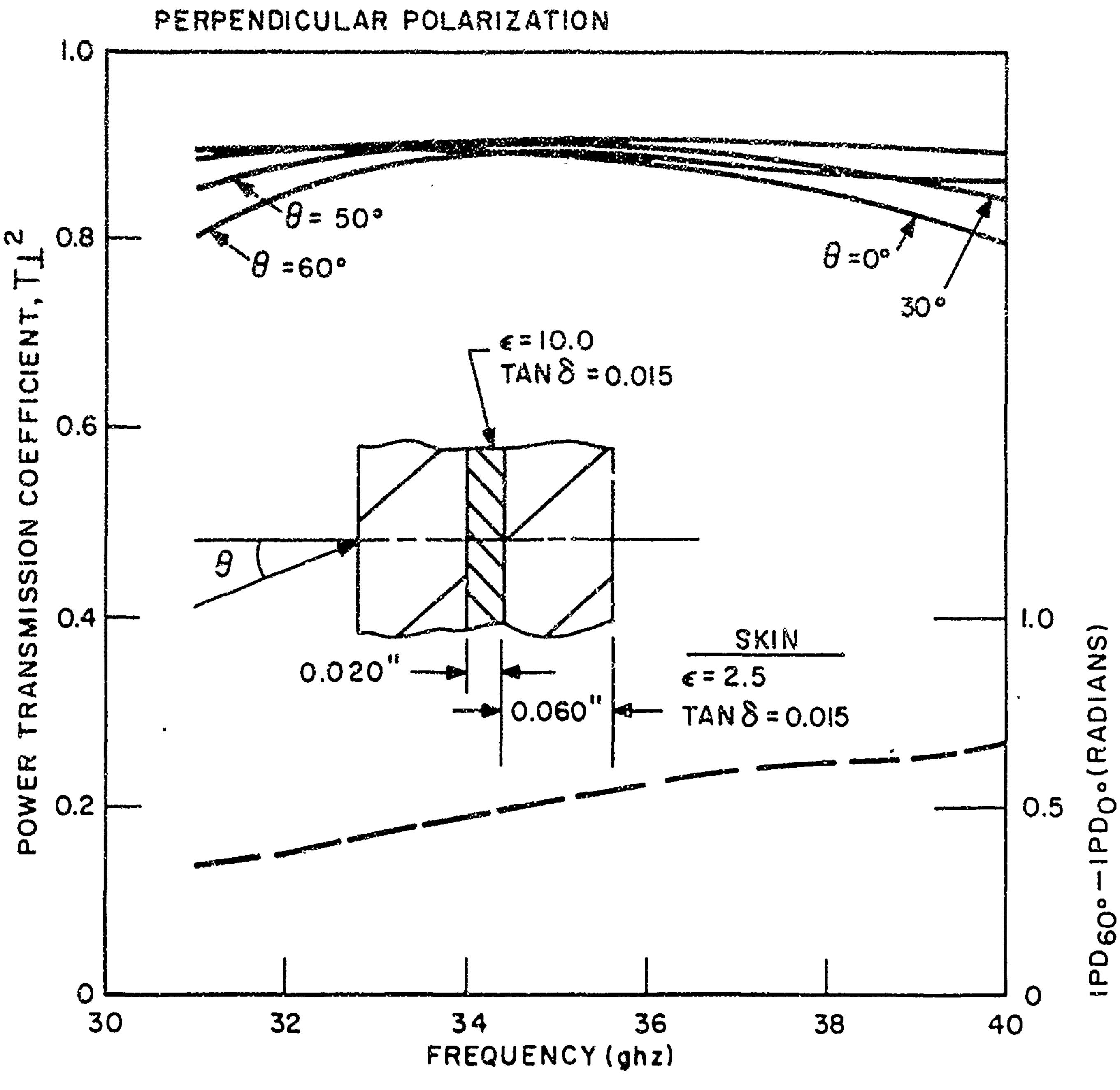

FIGURE 10 - Transmission and IPD Measurements Through Quarter-Wave-Skin Sandwich Panel (Core Dielectric 10.0)

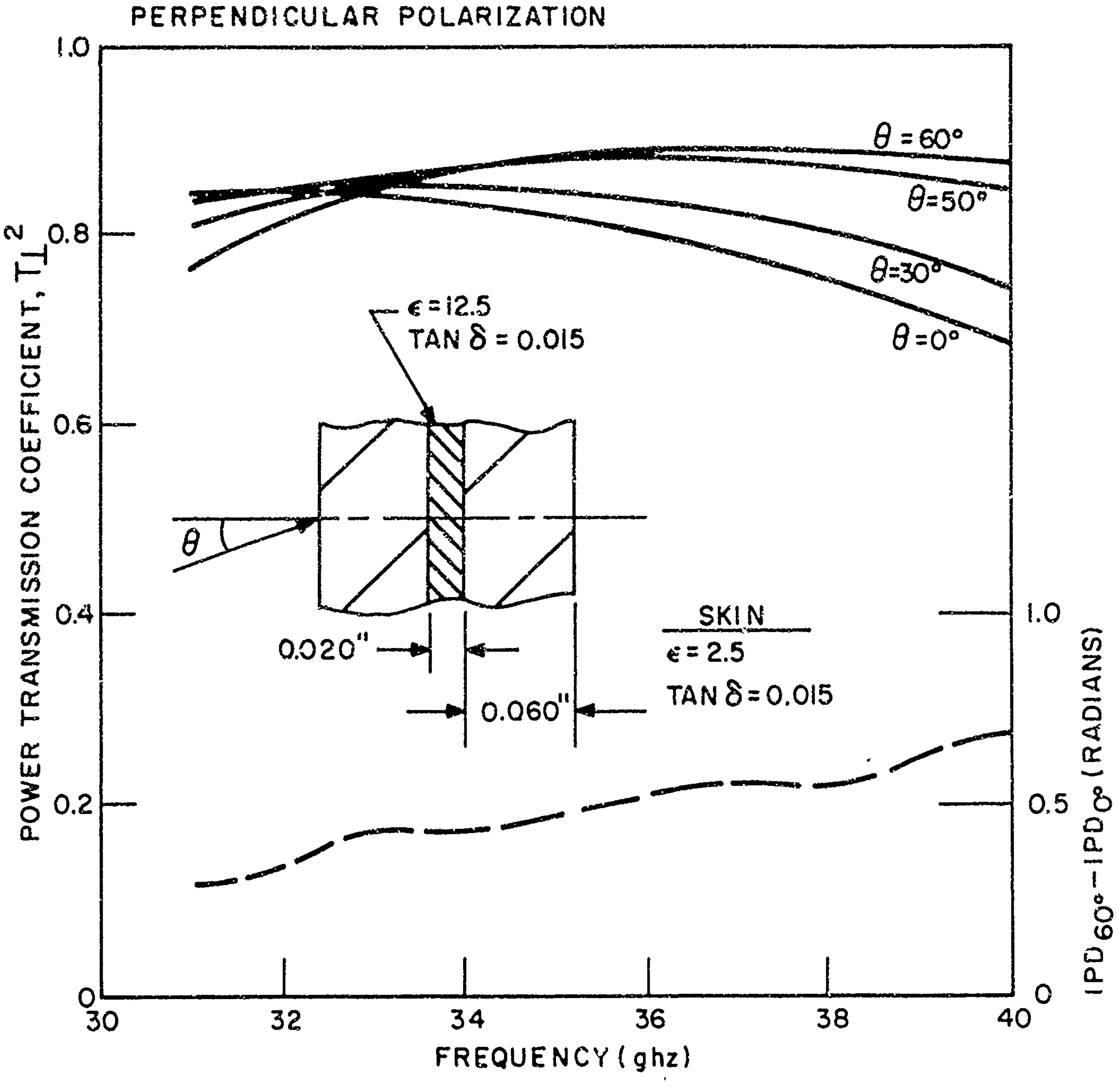

FIGURE 11 - Transmission and IPD Measurements Through Quarter-Wave-Skin Sandwich Panel (Core Dielectric 12.5)

with a higher dielectric material used as a core (load). This is consistent with the proof by Fano[2] that ideal matching structures are ideal filters. Increased performance in the pass band is accompanied by increased reflections in the stop band.

The dielectric constants of the B-sandwich skins and core are so chosen that the characteristic admittance of the skin material is the geometric mean of the admittances of the environment (air, $\varepsilon_o = 1$) and the core, all of which are functions of the angle of incidence (θ). (See equation (2).) The oft stated "square root of the core" is the special case of normal incidence. The normalized characteristic impedance (Z) in a medium (neglecting reflected waves) has been defined[3] as:

$$Z = 1/\left(\sqrt{\varepsilon - \sin^2 \theta}\right) = 1/Y; \tag{1}$$

and the admittance (Y) equation after squaring becomes:

$$Y_s = \varepsilon_s - \sin^2 \theta = \sqrt{(\varepsilon_c - \sin^2 \theta)(\varepsilon_o - \sin^2 \theta)} = \sqrt{Y_c \, Y_{air}}\,; \tag{2}$$

where subscripts

o = free space,
c = core, and
s = skin.

Note that for normal incidence ($\theta = 0°$), equation (2) is simply:

$$\varepsilon_s = \sqrt{\varepsilon_c} \tag{3}$$

The graphs of transmission are similar to the plot of some filter performance. This suggests application of the extensive literature on filters (and matching) to the radome design problem. Thus far, the B-sandwich remains the sole example, primarily because of the lack of physically rugged materials with low dielectric constants for the skins.

For most radome designs, the flexibility in the choice of dielectric constants is limited to the list of durable, inexpensive materials readily obtainable on the commercial market. The quarter-wave skins for Ka-band are reasonably thin for low-dielectric materials. The core, constructed of a higher dielectric material, can be varied in thickness and made sufficiently strong to be the prime load-bearing member. An example of a practical B-sandwich radome wall to accommodate the hypothetical Ka-band radome design is illustrated in figure 12. The quarter-wave skins

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2. *Matthaei, Young, and Jones; Microwave Filters, Impedance-Matching Networks and Coupling Structures; 1964; McGraw-Hill; Chapter 1.*
3. *Snow, O. J., 6 Apr 1953; Application of the Impedance Concept to Radome Wall Design; NAVAIRDEVCEN Report No. NADC-EL-52196.*

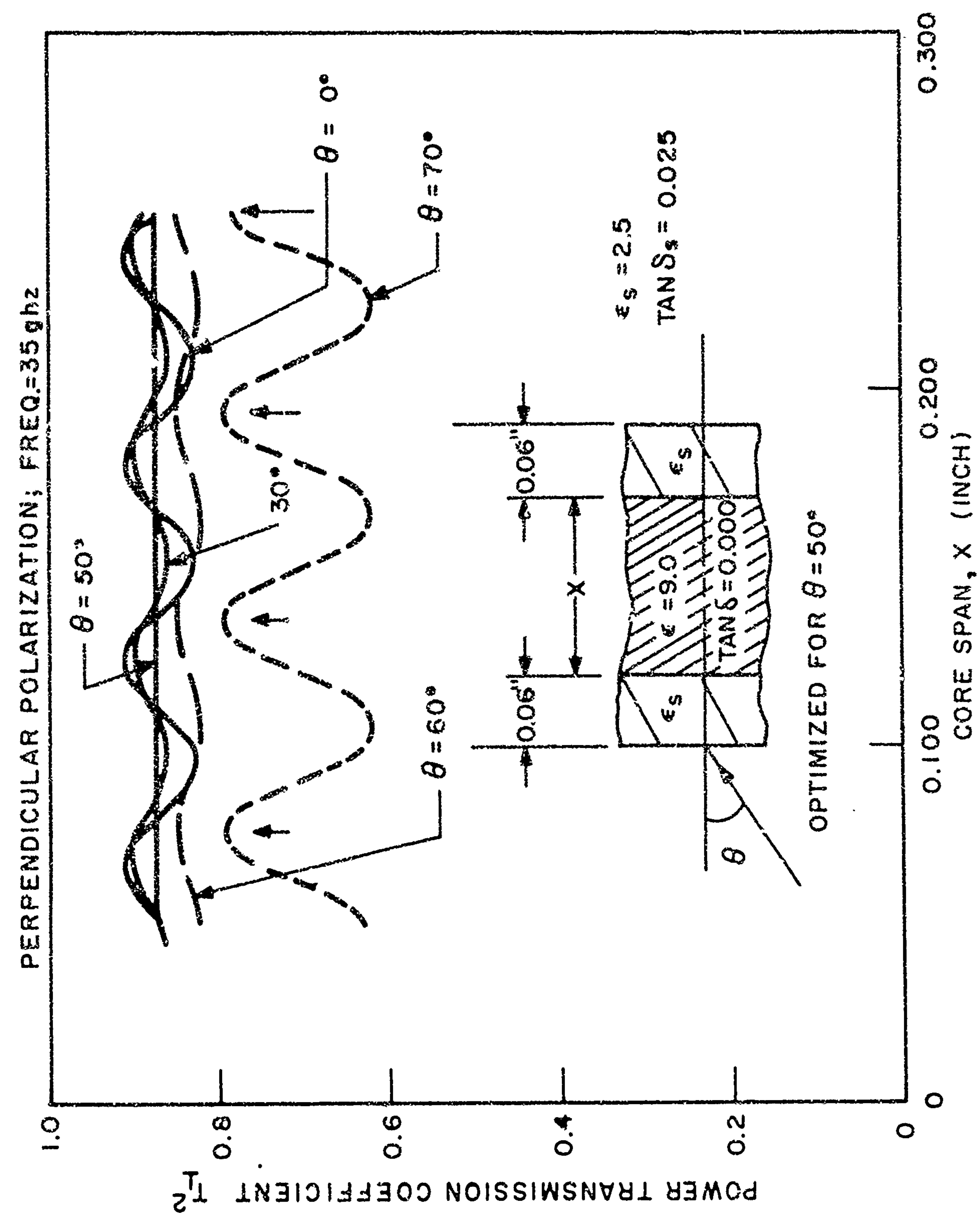

FIGURE 12 - Transmission Through a B-Sandwich Dielectric Panel

(transformers designed for 50 degrees incidence angle) are assumed to be of Duroid (reinforced Teflon) or of Polyphenylene oxide (PPO), both having a dielectric constant of approximately 2.5. The core dielectric constant determined by equation (1) should be 9.499. A material near that value is alumina ($\epsilon \sim 9.0$) and is chosen for the core.

The one-way power transmitted will remain equal to or above 82 percent, regardless of the choice of core thickness. Inasmuch as the skins are quarter-wave for 50 degrees incidence angle, the power remains constant at 87.7 percent for this incidence angle. There is some oscillation for the radiation incident at angles above and under the design angle of 50 degrees. Alumina has a low loss tangent ($\tan \delta \sim 0.0002$), and is therefore assumed lossless in figure 12. It can be seen that preferred choices of core thickness occur to optimize transmission. The weight requirement and the need to minimize the phase distortion, direct that the choice of wall span be a minimal value commensurate with the structural and aerodynamic demands.

BI-LAYER PANELS

An unusual but workable design is a radome wall made from two laminations of different dielectric materials each a half-wave in thickness. Because half-wave spans are relatively thin for most radome materials at Ka-band, such bi-layer radomes will not be excessive in weight for airborne application.

An example of such a design is to have an outer half-wave-wall shell of pyroceram bonded to an inner half-wave shell of glass-reinforced plastic. Figure 13 illustrates the transmission through a wall panel built to this configuration. The plastic wall thickness is 0.083 inch and is half-wave for normal radiation; the thickness of the pyroceram layer is varied and would depend on the anticipated variation of incidence of radiation (radome shape). The pyroceram veneer of 0.077 inch backed up by the 0.083-inch glass-reinforced plastic is a good choice to accommodate the hypothetical design problem previously considered.

Essentially, the half-wave bi-layer is a second-order radome, and when compared to that of the full-wave homogeneous plastic wall (figure 14), the transmission properties of the bi-layer are slightly superior. Also, the curve of the difference in the IPD shows that the phasing problem of the bi-layer is less critical than that of the full-wave wall. The total wall span is 0.160 inch, and is competitive physically with the full-wave wall.

An extension of this technique is to compare a wall design of a half-wave pyroceram veneer bonded to a full-wave panel of glass-reinforced plastic with the third-order plastic wall illustrated in figure 2. A bi-layer radome consisting of an outside pyroceram shell of 0.079-inch thickness and a glass-reinforced plastic substrate of 0.166 inch appears to be a good choice for the hypothetical design problem assumed

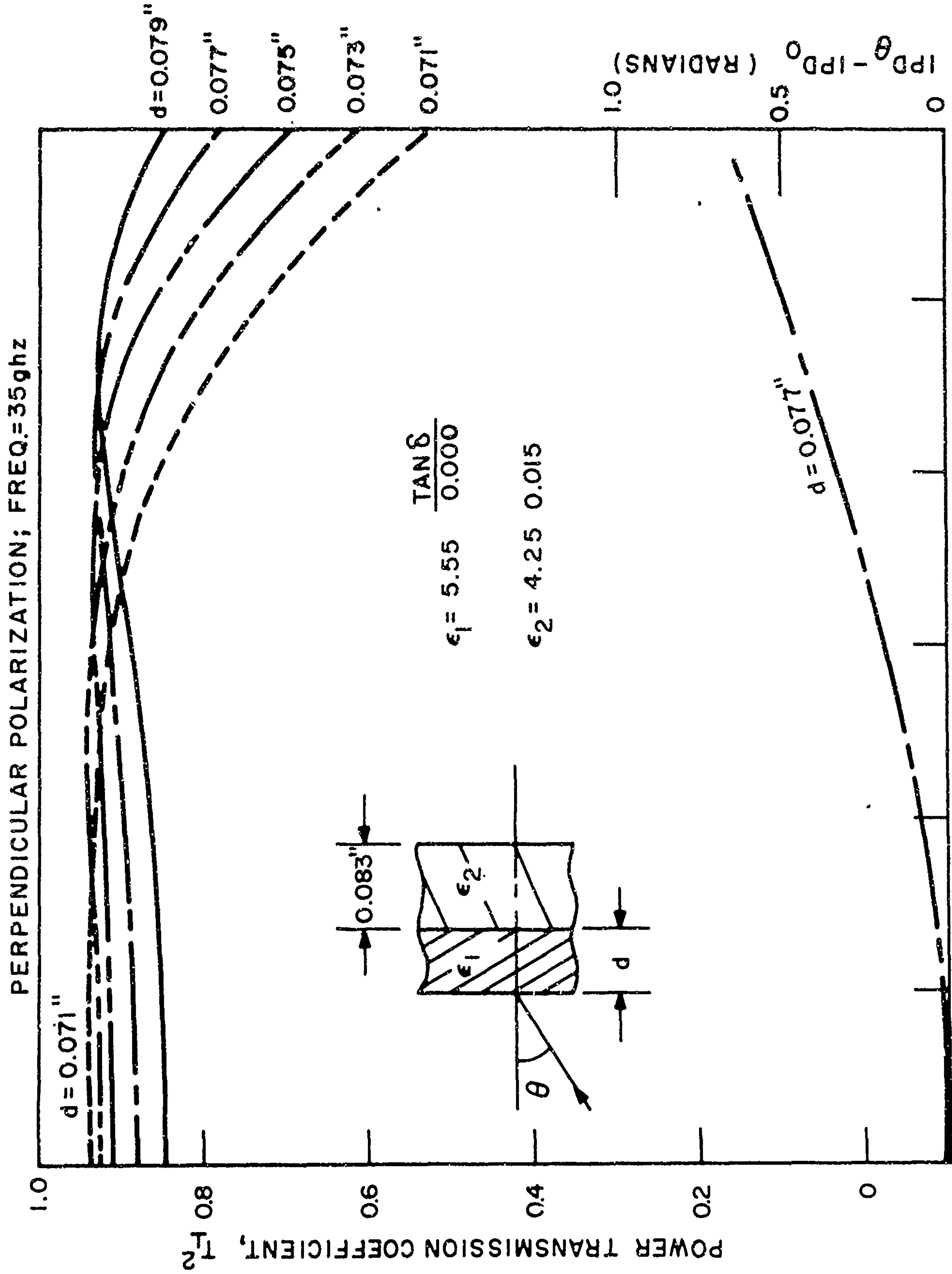

FIGURE 13 - Transmission and IPD Measurements Through a Bi-Layer Dielectric Panel (Thickness of Substrate = 0.083 Inch)

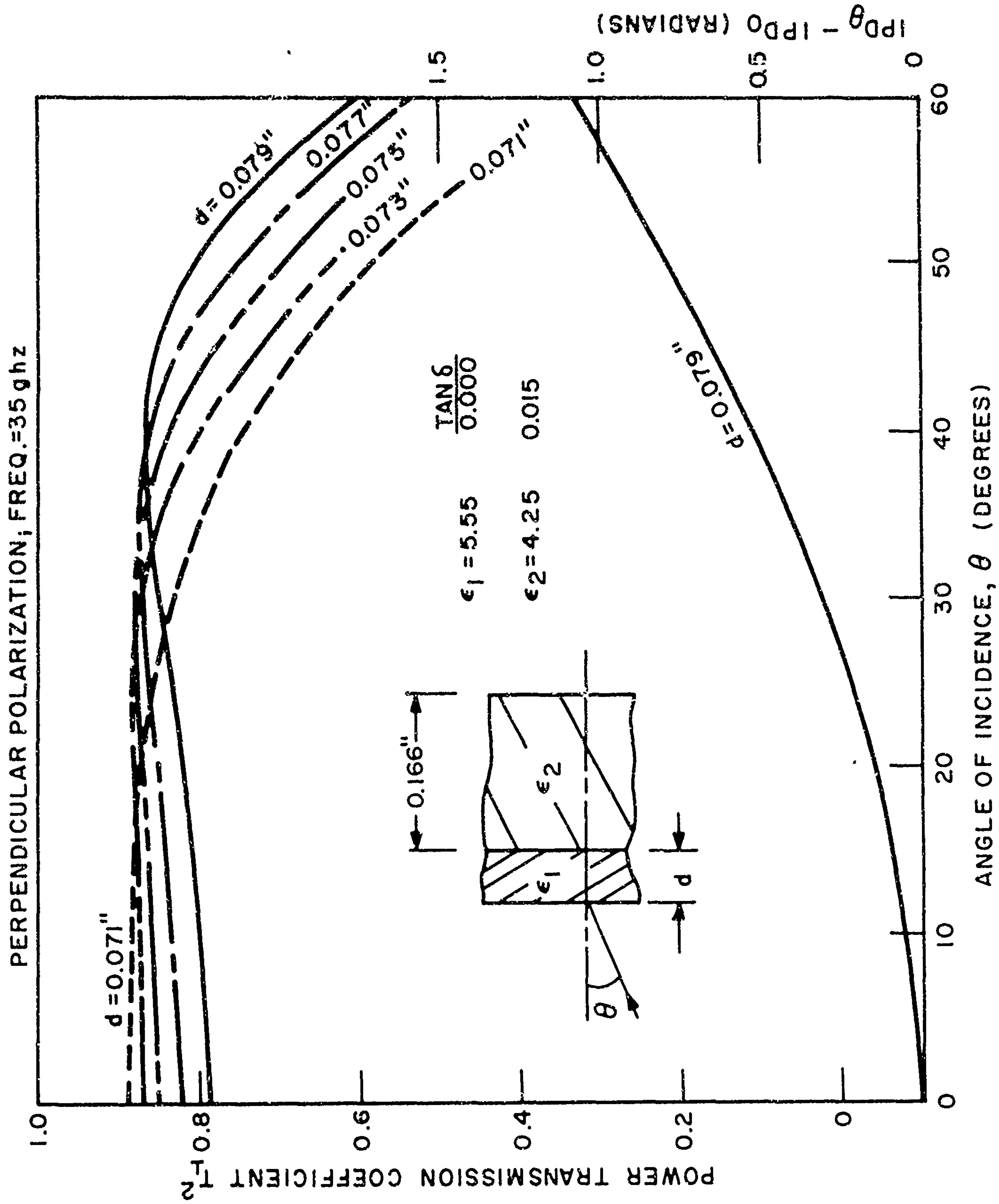

FIGURE 14 - Transmission and IPD Measurements Through a Bi-Layer Dielectric Panel (Thickness of Substrate = 0.166 Inch)

in this report. The total wall span is approximately a quarter of an inch. Figure 14 indicates that this bi-layer design is electrically superior to the third-order plastic design, with regard to both the transmission and the phase alignment.

It is to be noted that relatively high-dielectric materials can be used to advantage in the bi-layer construction, especially with materials having very low heat losses.

TRI-LAYER PANELS

An extension of the bi-layer design technique is to add an additional half-wave panel. Three half-wave panels of dissimilar dielectric materials form the tri-layer panel. For example, assume that a panel is constructed of pyroceram (ε_1), glass-reinforced plastic (ε_2), and a vinyl molding compound (ε_3). Figures 15 and 16 illustrate the theoretical transmission of 35 ghz power through such a panel. The thickness of the outer pyroceram layer is a parameter in both figures. The thickness of the other layers are fixed, half-wave spans (for normal incidence in figure 15 and for high incidence in figure 16). It is apparent that a few mils added or subtracted to any of the veneers can adjust significantly the transmission plot as a function of the angle of incidence.

Assume the tri-layer wall is to be applied to the hypothetical radome design problem. In figure 15, the second and third layers are half-wave panels for normal incidence, and a choice of 0.082 inch for the pyroceram layer will permit an average power transmission of approximately 78 percent. The minimim transmission is 72 percent and exceeds the minimum transmission required for the hypothetical radome. A look at figure 16, with the second and third layers half-wave for high incidence, suggests that a good choice for the pyroceram layer is 0.073 inch. This wall construction will also provide an average power transmission of approximately 78 percent. The IPD curves for both are comparable to the third-order homogeneous reinforced plastic wall (see figure 2).

To design a constant-wall, tri-layer radome that will accommodate radiation at variable incidence, the following technique can be applied. First, choose the veneer material with the lowest heat loss (or lowest dielectric constant if loss tangents are nearly similar) to be half-wave for the maximum angle of incidence. Then, fabricate at least one of the other veneers as a half-wave for the lowest angle of incidence. The choice of half-wave of the third veneer can be flexible, depending on where the emphasis is required to accommodate the majority of incidence. Ordinarily, if all angles of incidence are of equal importance, then the choice is to make the third veneer also a high-incidence, half-wave structure. Note that a tapered wall can be made by machining just a single veneer in the radome construction. The use of tri-layer radomes is limited to narrow bandwidths.

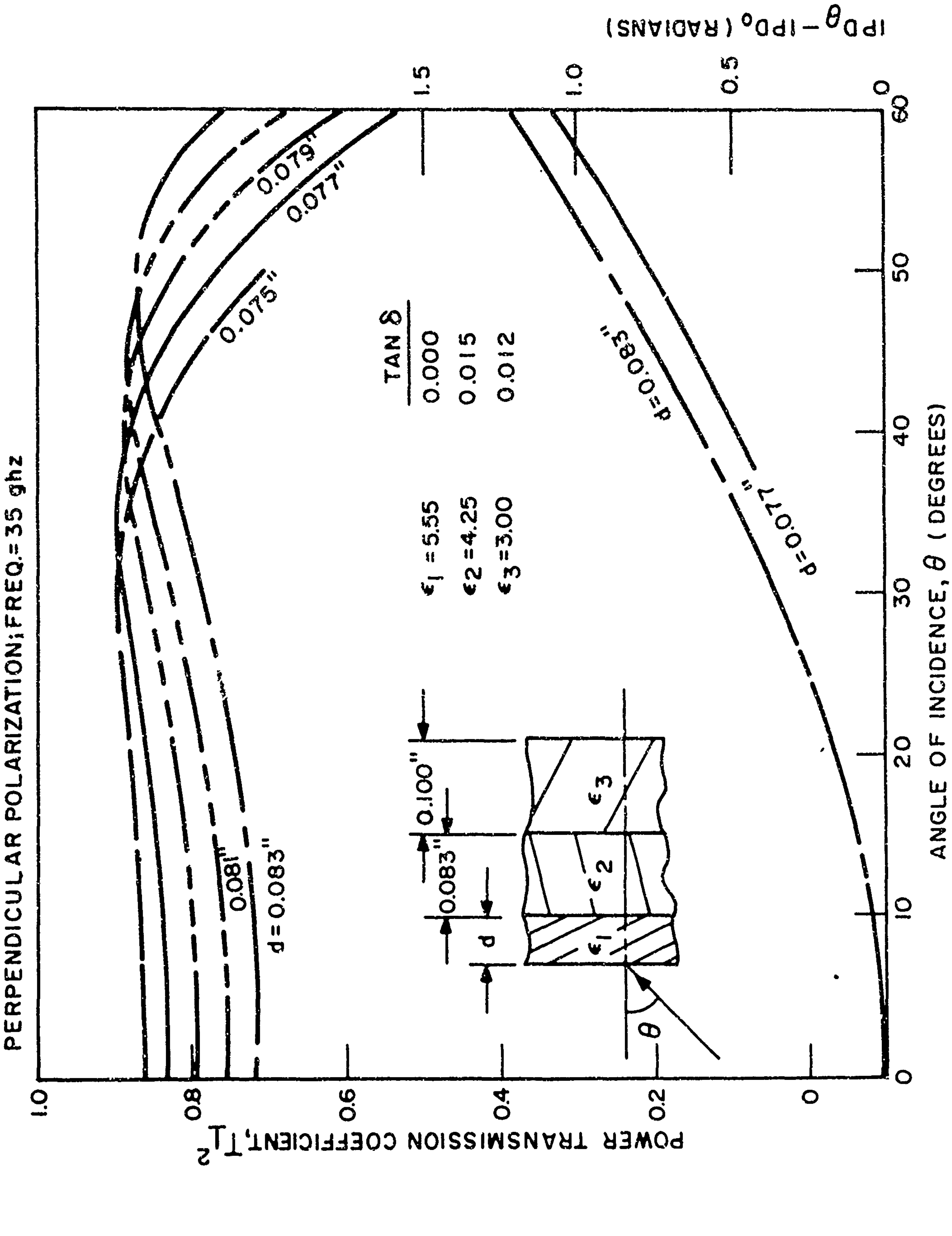

FIGURE 15 - Transmission and IPD Measurements Through a Tri-Layer Dielectric Panel (Thickness of Substrate = 0.083 and 0.100 Inch)

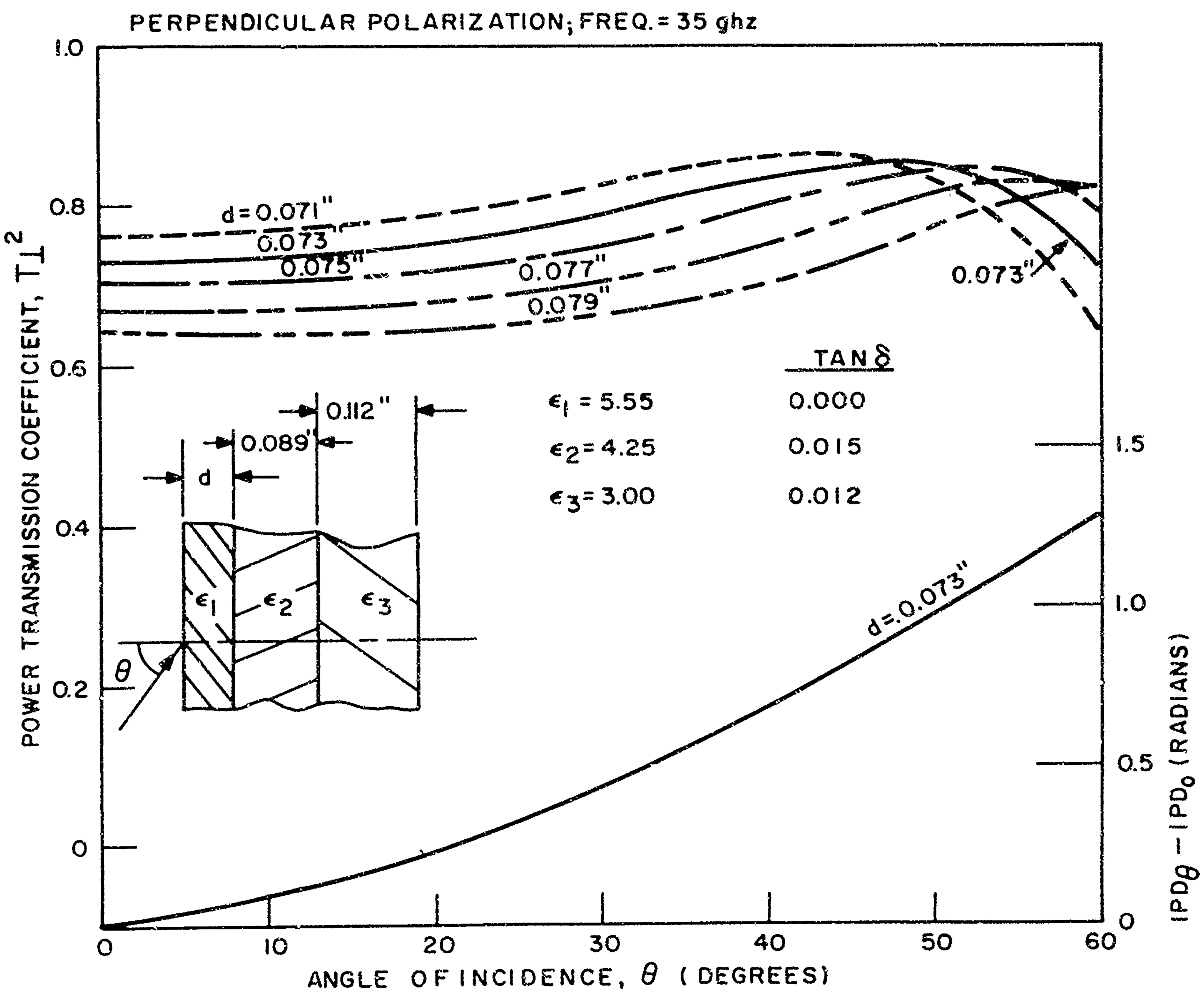

FIGURE 16 - Transmission and IPD Measurements Through a Tri-Layer Dielectric Panel (Thickness of Substrate = 0.089 and 0.112 Inch)

MULTI-LAYER PANELS

One radome concept relatively easy to study with the matrix form of the equations of transmission is that of the periodic structure. Here, a panel or set of panels is repeated to form the total structure. Some interesting phenomena occur in the transmission of perpendicularly polarized signals through these periodic structures. The dielectric wall behaves as a low-pass, equal-ripple filter, with the number of ripples equal to the number of repeated panels. The sharpness of the cutoff increases with increasing order, but the cutoff frequency is a function of the basic cell structure.

This report is not intended to cover an extensive study of multi-layer radome designs. However, a seven-layer panel is included to illustrate a broadband structure for the Ka-band frequencies. The design philosophy is to use two A-sandwich walls bonded together with an added layer of the core material. Figure 17 illustrates the change in transmission of power as this middle core (d) is expanded. The IPD data is also plotted (see figure 18) for a discrete choice of the core (d = 0.100 inch).

The dielectric materials used in this multi-layer panel are the familiar plastic wall structures. The A-sandwich segments are first-order designs optimized for an angle of incidence of 50 degrees. The thickness of each skin is 0.020 inch. The outer core spans are 0.053 inch. (Note that the standard phenolic honeycomb core material is usually cut to thickness values of one-eighth inch or larger.)

This seven-layer wall structure demonstrates the feasibility of multi-layer application to Ka-band radar. Figure 19 displays the transmission of power through the seven-layer panel (d = 0.100 inch) as a function of frequency. For the familiar radome design problem assumed in this report, such a wall design could be used for radar operating in the frequency band from 33.0 to 37.2 ghz.

DISCUSSION OF RESULTS

Table II lists in summary form the Ka-band radome wall types investigated during this analysis, and presents facts pertinent to their applicability.

The thin-wall, half-wave-wall, and first-order A-sandwich radomes cannot be used to house Ka-band radar antennas on an aircraft at positions exposed to severe air loadings. Second- and subsequent order thin-skin A-sandwich designs are not practical for Ka-band or higher frequencies.

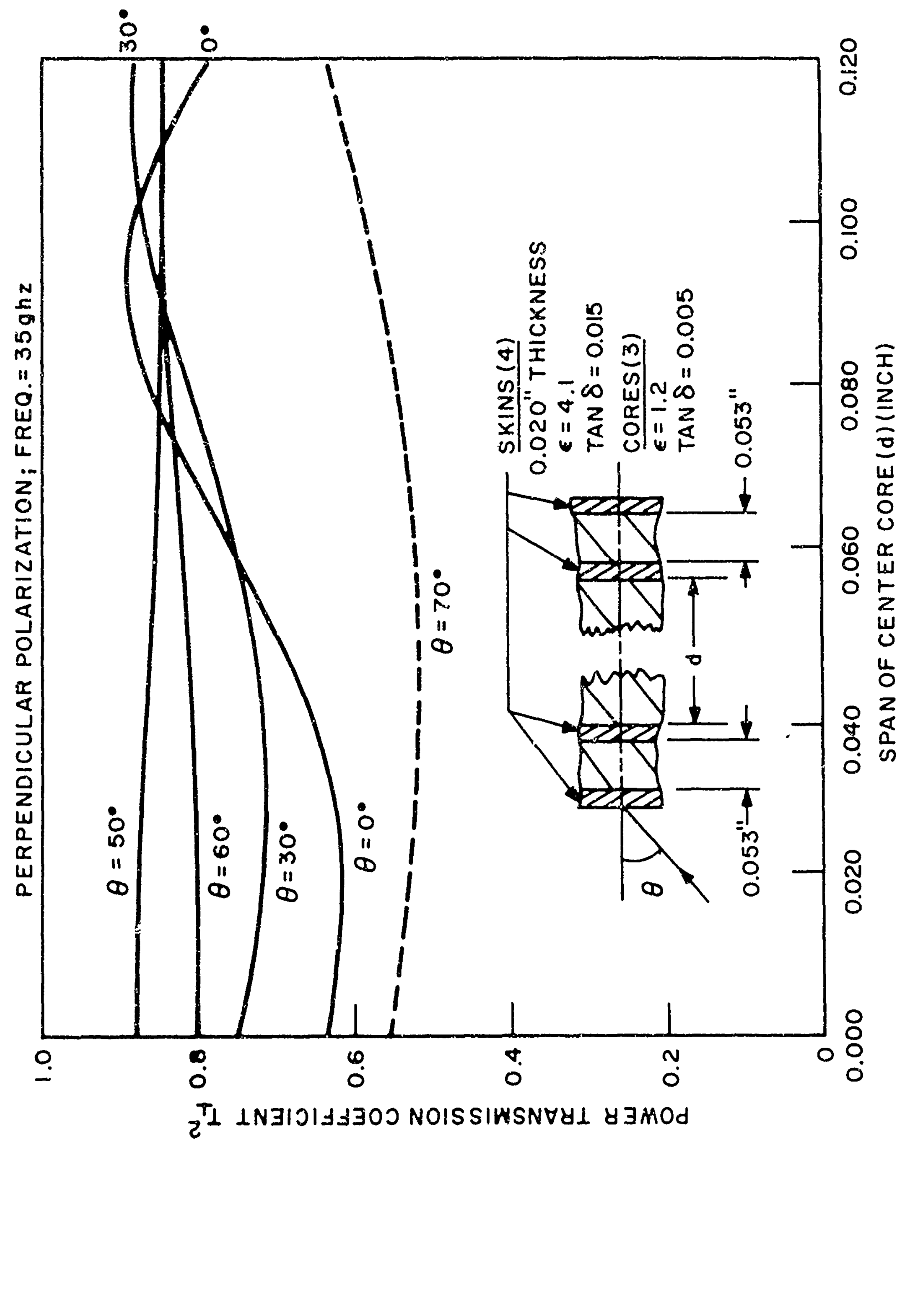

FIGURE 17 - Transmission Through a Variable Seven-Layer Dielectric Panel

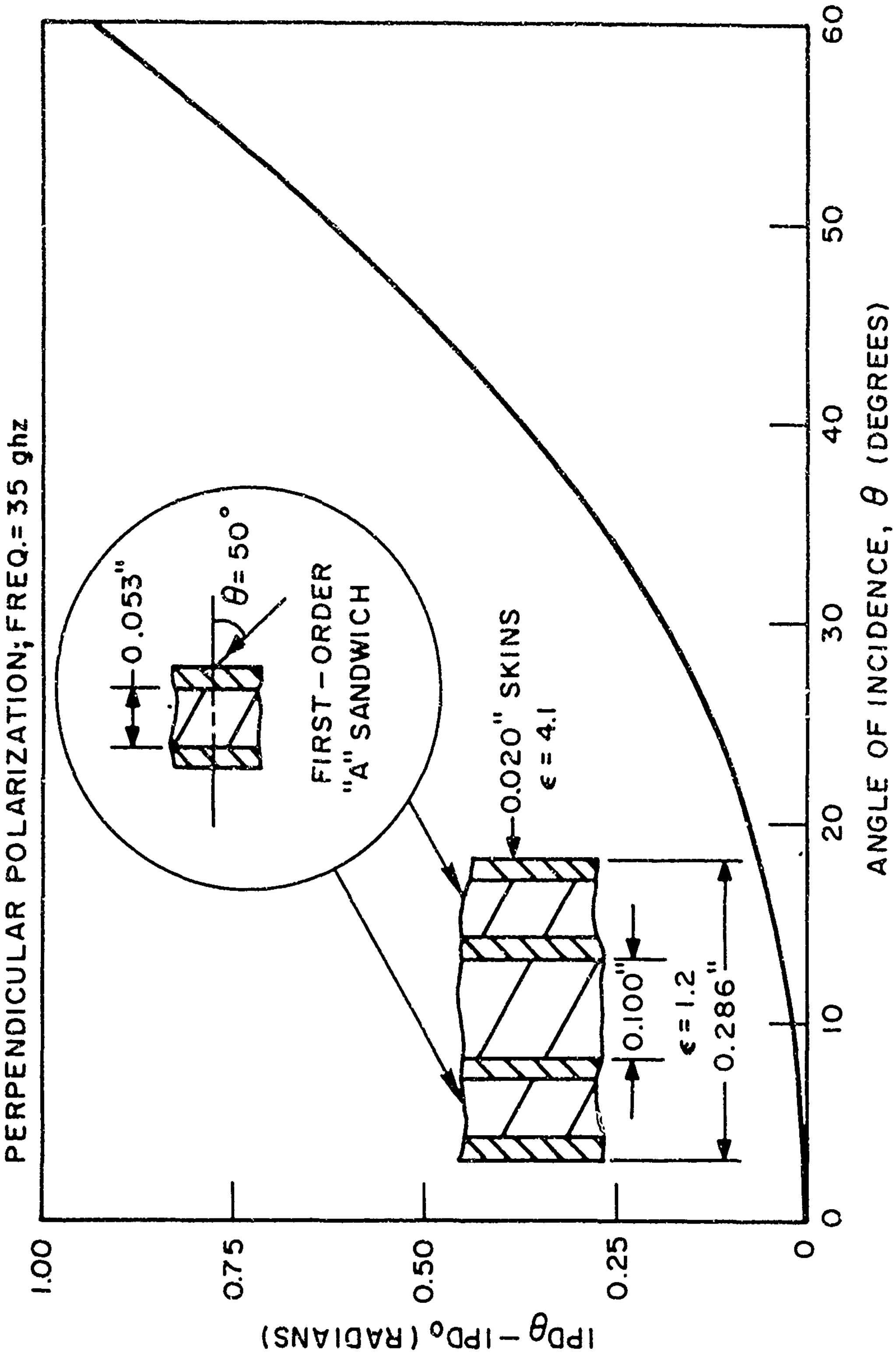

FIGURE 18 - IPD Measurements Through a Seven-Layer Dielectric Panel

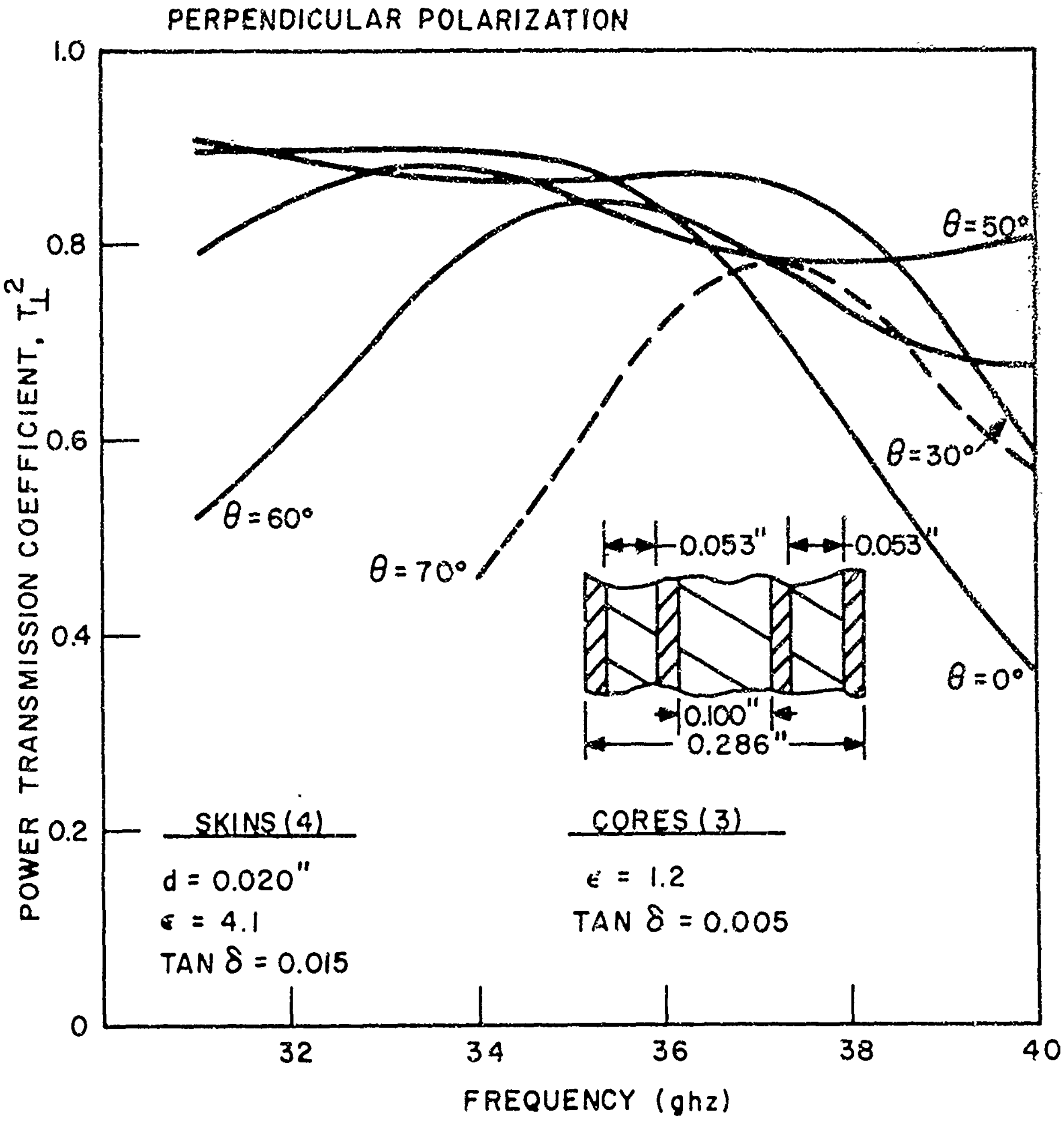

FIGURE 19 - Transmission Through a Seven-Layer Dielectric Panel as a Function of Frequency

The simplicity of construction and reasonable electrical properties of a full-wave wall design (provided it is physically adequate for the proposed position on an aircraft) make this a favorable choice for a Ka-band radome. More complicated designs employing half-wave veneers can provide better transmissibility for a narrow choice of frequencies. These include half-wave-skin A-sandwich walls, as well as bi-layer and tri-layer designs.

The B-sandwich radome is severely limited by the materials that may be used in its construction. However, this design permits a broad tolerance in its manufacture; can be made stronger by increasing the core with negligible effect on the electrical properties; and allows a broad bandwidth.

Any reasonable veneer of dielectric material used in the design of electromagnetic windows for millimeter wavelengths exceeds thin wall. An electrically thin wall is assumed to be much less than a quarter-wavelength through the material. Therefore, if airborne radar systems employ extensive use of these frequencies, it will be necessary to investigate new radome wall concepts.

Further study on the application of the multi-layer concept is recommended. Other studies of interest include investigation of tuned reactance walls and polarization controlling devices.

TABLE II

SUMMARY OF Ka-BAND RADOME WALL TYPES INVESTIGATED

Type of Wall	Typical Materials	Physical Strength	Construction Tolerance	Power Transmission	Broadband Capability
Thin Wall (zero order)	Glass-reinforced plastic	Very weak	Loose	Good	Limited
	Glass-ceramics	Very weak	Loose	Good	Limited
	Ceramics	Very weak	Loose	Fair	Limited
Half-Wave (first order)	Plastics	Weak	Average	Very good	Limited
	Glass-ceramics	Weak	Average	Very good	Limited
	Ceramics	Weak	Average	Very good	Limited
Full-Wave (second order)	Plastics	Good	Average	Good	Limited
	Glass-ceramics	Good	Tight	Good	Limited
	Ceramics	Good	Tight	Good	Limited
A-Sandwich (first order)	Glass-reinforced plastic skins - honeycomb core	Weak	Average	Good	Fair
(second order)	Glass-reinforced plastic skins - honeycomb core	Good	Tight	Poor	Poor
Half-Wave-Skin Sandwich	Glass-reinforced plastic skins	Very Good	Average	Good	Fair
	Glass-ceramic skins	Very good	Average	Very good	Fair
B-Sandwich	Plastics, laminated fiberglass, and ceramics	Good*	Loose	Good	Good
Bi-Layer	Plastic and glass-ceramics	Good	Tight	Good	Fair
Tri-Layer	Plastic and glass-ceramics	Good	Tight	Fair-Good	Limited
Seven-Layer	Laminated fiberglass - honeycomb core	Good	Excellent for low angles of incidence		

* Skins should be of a material to withstand rain and heat erosion.

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13. ABSTRACT

Standard and nonstandard types of radome wall structures are discussed to aid in determining practical design concepts for radar systems operating at Ka-band frequencies. Transmission efficiencies of selected radome panels are illustrated and compared for a hypothetical radome design problem.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
RADOMES DIELECTRICS MILLIMETER WAVELENGTHS						